Technical Paper 284

FACTORS IN DESIGN OF HARDCOPY TOPOGRAPHIC MAPS

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BATTLEFIELD INFORMATION SYSTEMS TECHNICAL AREA

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A literature survey on factors in map design, including visual coding techniques and assessment techniques, is summarized in this report, as the first step in improving legibility and usefulness of hardcopy (printed) topographic maps.

Map design determinants are scale, interrelatedness of symbols, and a body of standardized symbols and modes of coding. Map scale influences fidelity, → next page

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as small scale requires selection, simplification, and magnification of features. Clutter can be reduced by coding to differentiate information: color coding aids in identification and reduces location time; iconic and alphanumeric shape coding can be learned easily and are flexible; size coding requires considerable space and increases location time.

Among map assessment techniques, opinion sampling is relatively inexpensive but does not measure actual performance, and theoretical analysis is a limited first step only. Empirical analysis measures performance with the map product, either by assessing performance directly or be measuring the map-reading skills which underlie performance.

In comparisons of different types of hardcopy topographic maps, the best photo-based maps produce performance comparable to that with conventional line maps. Some Army users preferred to augment contour lines on conventional maps with layer tints for interpreting topographic relief. Future airborne map displays should consider the information requirements of pilots, effects of vehicle movement, and map legibility in poor light.

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FOREWORD

The Battlefield Information Systems Technical Area of the U. S. Army Research Institute for the Behavioral and Social Sciences (ARI) does research on tactical information systems and displays used to present tactical information to military personnel. Maps provide information on locations and terrain, either as displays, for instance on a screen, or as hardcopy printed on paper. The present Technical Paper summarizes the preliminary research for a project to improve legibility of hardcopy topographic maps.

Work was done under Army Project 2Q162106A732, in coordination with the Army Engineering and Topographic Laboratory.

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FACTORS IN DESIGN OF HARDCOPY TOPOGRAPHIC MAPS

BRIEF

Requirement:

To summarize, from existing research literature, the principles of map design and visual perception relating to improving readability of hardcopy topographic maps.

Procedure:

Findings from pertinent literature were critically analyzed and integrated to provide a coherent summary of visual coding techniques, assessment techniques, and principles of design germane to hardcopy topographic maps.

Findings:

Three important determinants of the design of topographic maps are scale, interrelatedness of symbols, and a body of standardized symbols and modes of coding. Map scale is an important determinant of fidelity. If the same rules are used to represent features on maps of different scale, then the larger scale map will have greater fidelity because small scale necessitates selection, simplification, and magnification of features. Enlarging or reducing a map photographically will not alter fidelity of a map.

The problems of clutter and overlapping symbols occur when too much information is crowded onto a map. Clutter can be reduced by presenting information on separate, subsidiary maps, or by use of coding to differentiate information.

Visual coding techniques applicable to maps are color coding, shape coding, and size coding. Coding categories may be based also on number of visual codes used and the way in which they are combined. Color coding aids in identification and search, and decreases location time.

Redundant coding using both shape and color decreases location time over use of shape coding alone. Iconic shape coding can be learned easily, however, alphanumeric symbols can be designed for easy learning and are more flexible. Size coding requires considerable space and increases location time.

Three assessment techniques used to evaluate maps are opinion sampling, theoretical analysis, and empirical analysis. Opinion sampling is relatively inexpensive and easily carried out but does not measure actual performance.

Theoretical analysis provides a necessary first step but is limited in that it is rarely possible to specify all factors that might influence performance. Empirical analysis measures actual performance with the map product, either by assessing direct or simulated performance with the map or by measuring map-reading skills which underlie performance.

The best photo-based maps produce performance comparable to that of conventional line maps now in use. However, importance of differences in what orthophoto maps and line maps portray does not seem to have been investigated.

Some Army users have reported difficulty interpreting topographic relief from contour lines. In one survey, a majority of Army users stated that the most effective manner of relief portrayal is contour lines augmented with layer tinting.

Studies on airborne map displays produced a body of suggestions for design of future airborne maps, on the information requirements of pilots, effects of movement, and map legibility.

Utilization of Findings:

Principles and data from the literature survey summarized in the present report were used to design a technique for assessing relief maps, part of an ongoing project. The assessment technique will be used in turn to determine the best way to portray terrain relief on hardcopy maps.

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FACTORS IN DESIGN OF HARDCOPY TOPOGRAPHIC MAPS

INTRODUCTION

A topographic map is defined as a mathematically determined presentation of a portion of the earth's terrain and landforms, systematically depicted to scale upon a plane surface. Manmade and natural features are shown using symbols, lines, colors, and shapes. Relief is normally represented by contour lines.

In the present report, discussion specifically refers to topographic maps, although many of the principles apply to maps in general. Portions of this paper have been published as: Potash, L. M. Design of Maps and Map-Related Research. Human Factors, 1977, 19(2), 139-150.

Hardcopy topographic maps are typically multipurpose displays that have to meet the needs of a variety of users. They must portray a large quantity of spacially overlapping geographic information, which can result in clutter and interference among symbols if the map is not well-designed. This paper will summarize and organize literature related to the design of hardcopy maps and map research.

The first portion of the paper defines and discusses characteristics of hardcopy maps which, if ignored, can lead to faulty problem definition and to research having little applicability to hardcopy maps.

The second section reviews literature on cartography, visual displays, coding, and visual perception. The last section discusses different techniques used in map research and summarizes research on extant maps.

CHARACTERISTICS OF HARDCOPY TOPOGRAPHIC MAPS

Three characteristics of hardcopy topographic maps that tend to distinguish them from other kinds of displays are: (1) map scale, (2) interrelatedness of symbols, and (3) a body of standardized symbols and modes of coding. Clutter, though not an inherent feature of hardcopy topographic maps, is a common problem.

Map Scale

Map scale is an important determinant of accuracy and completeness of geographic information. Scale refers to the ratio of cartographic dimensions to those in the actual terrain (i.e., a centimeter on a 1:50,000 scale map represents 50,000 cm in the "real world)."

Fidelity of a map depends on both the scale at which the map is constructed and the smallest area on the map in which the feature can be adequately defined and described. (Grabeau and Addor, 1964).

If drafting or production of a map is in accord with its scale, then fidelity will decrease with decreasing map scale because use of a smaller scale necessitates greater selection, magnification, and simplification.

Selection refers to the fact that features too small to be drawn to scale will either be deleted or magnified depending on their importance to the overall purpose of the map. When selection is necessary, consistency of treatment is often mandatory. Thinning out detail in a complex portion of a map, coupled with retention of comparable detail in a less complex portion, can mislead the map reader. (Montagano, 1962).

Magnification refers to the exaggeration of some features in order to display them at a given map scale. On a 1:250,000 scale map the prescribed symbol for a road is equivalent to a road approximately 158 m wide on the ground.

Simplification is a type of selection and refers to deletion of details or "smoothing out" of a feature. As scale decreases, lines used for outlining objects represent increasingly greater widths. Details, such as curves in the road, must be omitted because showing them results in too great a magnification and displacement. At progressively smaller scale, magnification of certain features becomes impractical; use of group symbols or outlines becomes necessary. (Floyd, 1962).

Map symbols indicating position have been classified as point, line and area symbols. (Adams and Dip, 1967). A point symbol is a mark standing for a feature which is given location as a point. The feature's horizontal and vertical dimensions are not indicated by the symbol.

A line symbol is a mark or series of marks standing for a feature which is given location as a line. Only the linear extent of the feature is represented by the line symbol.

An area symbol is a mark or series of marks standing for a feature which has given location as an area. The extent of the feature in the horizontal plane is represented by the area symbol.

A fourth category of positional symbol to add to the foregoing is three-dimensional symbols, i.e., those symbols representing the position of a feature in three dimensions.

The degree of indeterminacy of the exact position of a feature represented by a point symbol - assuming constant size of the symbol - is proportional to map scale. Minimal separation between features necessary for their individual depiction on the map increases as map scale gets smaller.

Features represented by line and area symbols require increasing simplification, deletion, or magnification with decreasing map scale.

In choosing scale for a given map, one has to consider the degree of simplification that is permissible for coding the different features on the map.

If relatively small sinuosities in a road are important landmarks for a certain task, then a large scale must be used. If appropriate, labelling such as "straight" or "zig-zag" may be used to compensate for the loss of detail caused by simplification.

Identifying characteristics of features change with scale. At small scale a long point of land might be the predominant characteristic of a coastline, while at large scale the drainage and inlets might provide the principal identifying characteristics.

By far the most ubiquitous three-dimensional symbol used on maps is the contour line. Strictly speaking, each individual contour line is a line symbol portraying points of equal elevation in the terrain. It is the pattern of contour lines that portrays the three-dimensional landscape. The pattern of contour lines is very much affected by map scale. Contour lines 0.63 cm apart on a 1:25,000 scale map will be only .15 cm apart on a 1:100,000 scale map. Consequently, the 6 m interval used on the 1:25,000 scale map must be changed to 18 or 24 m for the 1:100,000 scale map. This means that a prominent 34 m hill that is coded with five contour lines on a 1:25,000 scale map will be coded with only one contour line in the 1:100,000 scale map. The five contour lines portraying the hill on the 1:25,000 scale map can code steepness of slope and pattern of slope change. One contour line on the 1:100,000 scale map tells us nothing about the slopes to be found on the different sides of the hill. Of course, the size of the landform is also decreased in the small scale map. Since four contour lines are omitted, the hill may occupy a considerably smaller area than 1:16 of the area portrayed on the 1:25,000 scale map.

To test the effects of scale on a given type of line map, one has to be sure that the maps are produced in accord with normal procedures for maps of the given scale. If the contour interval is 18 m on the 1:50,000 scale version, than it could be 9 m on the 1:25,000 scale version.

Photographically enlarging a line map cannot change the map's fidelity. The enlargement can change only the perceptual accessibility of the information in that the visual display facing the viewer is changed. For instance lines are thicker, and the size of the features are changed so that small features may become more apparent. Also, larger features may become so enlarged as to make visual integration more difficult.

Alphanumeric symbols, an important category of nonpositional symbol, are affected by scale when the size of the object that they designate is scale-dependent.

A small feature may require relatively small print to assure that the label is associated with it. If small-scale maps tend to contain a greater number of significant features per unit area than comparable large-scale maps, they may require more selection in terms of what features are labelled.

Arbitrary-sized symbols cannot be used for assessing different types of coding for maps. In map displays, symbol size is often severely constrained due to scale and the existence of adjacent symbols.

Interrelatedness of Symbols

The second important characteristic of hardcopy maps is the interrelatedness of symbols. When density of one symbol is reduced, interdependence among symbols may entail reducing density of related symbols.

Symbols compete for saliency, and a high density of symbols may interfere with the ease of extracting information from a map. This interference as measured by increased time or decreased accuracy for extraction of a given kind of information from the map is said to indicate clutter.

A limit to the density of features is partly determined by the graphic form of those features, and the most appropriate graphic form is in part determined by density of features. (Adams and Dip, 1967).

Where there is physical overlap or juxtaposition of symbols, extraction of information may also be hindered due to alteration in the appearance of one or both symbols.

Simultaneous contrast results in changes in appearance of symbols. Complementary or near complementary colors when in juxtaposition enhance the intensity of one another. (Robinson, 1952).

Combining colors alters the hue of original colors. For example, adding layer tints to shaded relief changes original colors in that tints are darker than if shown on a white background. If a key is made up on the basis of tints as they would appear if printed on a white background, then no colors shown on the key will appear on the map.

Interrelatedness of map symbols means that research related to map displays cannot rely on "simplified" map stimuli or displays presenting limited portions of information normally found on maps. New methods of coding must be embedded in realistic map displays if their effectiveness is to be assessed. Interrelatedness of map symbols also means that map research must frequently entail simultaneous variation of more than one factor at a time. For example, if one wants to test the effect of using layer tints for elevation as contrasted with contours by themselves, then one automatically excludes use of layer tints for vegetation. If ability to extract information about vegetation from the map is also of interest, it is legitimate to contrast a map with contour lines plus layer tints for vegetation with a map using contour lines and layer tints for elevation plus iconic figure coding for vegetation.

Standardized Symbols and Modes of Coding

A third characteristic of hardcopy topographic maps is that of standardized symbols and modes of coding. With regard to military topographic maps, some of the standardized colors listed in Army Field Manual 21-31 are:

(1) black for the majority of cultural or manmade features;

(2) blue for hydrographic features such as lakes, rivers, and swamps;

(3) green for vegetation such as woods, orchards, and vineyards;

(4) brown for all relief features such as contours; and

(5) red for main roads, built up areas, and special features.

As for shape coding a number of topographic symbols have been standardized.

Contour lines represent a relatively standardized mode of relief portrayal.

Standardized conventions already existing must be taken into account in map-related research and design. The techniques and means for making the standard symbols are already present.

Cost effectiveness of altering these symbols must be considered in addition to the increase in intelligibility resulting from their employment.

If the conventions currently in use are altered, then there is the possibility of a decrement in performance due to interference from previous learning. This should be considered when choosing subjects for map-related research and may warrant sampling the appropriate user groups.

The Problems of Clutter and Alteration in Physical Appearance of Symbols

As indicated earlier, clutter refers to the fact that the speed and accuracy of symbol location in complex displays is affected by the number and nature of irrelevant symbols (for the problem at hand) in the display. As the number of irrelevant symbols increases, there is an increase in required search time and accuracy may decrease.

Clutter may hinder integration of information contained in the map. Where there is physical overlap or close juxtaposition of symbols, extraction of information may be hindered due to alteration in the actual appearance of one or both symbols (see "Interrelatedness of Symbols").

Two ways of combatting clutter and alteration in appearance of symbols applicable to hardcopy maps are:

1. Use of more than one physical display for presenting information.

2. Use of coding to differentiate information.

The first solution would mean construction of a number of special purpose maps containing the information necessary, for only the particular function for which the map is to be used. This solution has several disadvantages in that it would:

1. Increase time and expense for map construction.

2. It would add to the logistic problem in that a number of versions of the map might have to be supplied.

3. It causes difficulties if the information on two different maps must be correlated.

4. The user who has maps related only to a given function may be at a disadantage if the function changes quickly and he doesn't have the appropriate map available.

One modification which helps to alleviate some of these difficulties is to include a number of specialized relatively small scale maps of the same area in the margin or on the reverse side of the primary map. These supplementary maps may contain information such as elevation guides and flight obstacles, soils, trafficability, etc.

Regardless of cartographic technique used, there is a limit to the amount and type of feature that can be simultaneously represented on a map sheet. The only feasible solution in some instances is to use spatially separate maps of the same area, each portraying different features as well as features in common, to allow correlation between the maps.

The second solution, to differentiate information via coding, should be used always regardless of whether some of the information is also displayed on special purpose maps. In any map one wants to use efficient rather than inefficient or confusing coding techniques.

The importance of using the most efficient coding techniques increases as the number and type of features to be portrayed in a given map increases.

IMPLICATIONS OF VISUAL DISPLAY RESEARCH FOR MAP DESIGN

This section of the paper is devoted to different types of coding used in visual displays and an evaluation of the applicability of these coding techniques for use in hardcopy maps.

Some visual coding techniques that should be applicable to maps are color coding (hue, brightness, saturation), shape coding (iconic coding, arbitrary representation), and area size coding.

Coding categories may also be based on the number of visual codes that are combined in the coding process and the way in which they are combined.

Examples of these types of coding categories are given below (Meister and Sullivan, 1969):

(1) Single Coding
Example: 4 = 400 km/h

(2) Redundant Coding
Example: $\boxed{4}$ = 400 km/h (Both numeral and square indicating 400 km/h)

(3) Compound Coding
Example: △4 = 400 km/h (numeral means 400 km/h, triangle means jet-powered aircraft)

Most of the research reviewed in this section has utilized relatively small, discrete geometric symbols, rather than extended irregular symbols such as roads, contour lines, layer tints, and shading.

Color Coding

The term color coding is used in this review to indicate coding that utilizes different hues with a high saturation though it is understood that differences in brightness and possibly saturation also may contribute to the discriminability of the colors used in coding.

An extensive review and analysis of color coding research for visual displays produced the following conclusions (Christ 1975):

If the color of a target is unique for that target and is known in advance, color aids both identification and searching. With both multidimensional and unidimensional displays, color can be identified more accurately than size, brightness, geometric and nonalphanumeric shape codes.

Alphanumeric shape codes tend to be identified more accurately than color codes. When colors are added to an achromatic display, accuracy in identifying achromatic target features decreases relative to a monocromatic or achromatic display.

The few studies available concerning use of color as a redundant variable in identification tasks show a positive effect on accuracy.

Subjects require less time to locate or count colors in a display than when other types of coding such as size, brightness, or shape (Including alphanumeric symbols) are used. Redundant colors can decrease search time in symbolic displays if the subject knows the color of targets.

Using color in a pictorial display to provide a "natural" representation of the real world can decrease search time. In partially redundant color-coded displays, gain in search performance decreases as the proportion of nontargets with the same color as the target increases.

When partially redundant color is added to a search display and the subject does not know the color of the target, search performance is generally degraded.

A related finding is that memory of target color deteriorates less than does memory of target size; orientation, or shape. When subjects must identify and remember several independent features of a briefly exposed target, the accuracy of delayed reports of colors is only slightly reduced over immediate reports. By comparison, accuracy of shape and size reports is more affected if the report is delayed.

Comments found in the literature on other advantages of color coding are the following: McCormick, 1970; Meister and Sullivan, 1969; VanCott and Kinkade, 1972:

(1) When brightness contrast is low, color contrast can improve visual acuity appreciably, but acuity is increased much more by increasing brightness contrast.

(2) Colors are orientation-free in terms of coding.

(3) Color can be superimposed on shape without distorting it.

(4) Some colors are more resistant to human performance decrements than others; red is preferable for distance viewing, and yellow-greens are best for tasks demanding high acuity.

Literature reviews indicate that eight or nine maximally saturated colors are the maximum number that should be used for color coding. (McCormick, 1970; Meister and Sullivan, 1969; VanCott and Kinkade, 1972). This restriction is, at least in part, a result of the limitations of long-term memory under the absolute discrimination conditions that usually have been employed in color-coding studies.

The existence of a key that eliminates the long-term memory requirements may increase the number of colors that can be used successfully. (Shontz, Trumm, and Williams, 1968). Use of a key plus use of numbers, patterns (shape coding), and hues to form compound symbols allowed production of a map showing 116 different types of "potential natural vegetation" areas in the United States.

The numbers were used to differentiate the natural vegetation areas further and to assure quick access to the appropriate symbol in the key. (Kuehler, 1964). Use of patterns allowed assignment of several meanings to the same color, one meaning being associated with each pattern.

Limitations of color coding are:

(1) Color perception is very much affected by lighting conditions. Very low levels of illumination negate use of hues in coding and red light used at night can filter out colors or make them appear as grays. (Yanosky, 1967).

(2) About 6% of healthy males have reduced sensistivity to color, and .003% of males are completely color blind. (See VanCott and Kinkade, 1972 for a list of nine colors that can be recognized by both color-sighted and color-blind people).

(3) Combination of colors alters the original hue (see section, "Interrelatedness of Symbols").

In terms of background effects on legibility of printed matter, white on black, black on white, black on yellow, and black on green are good color combinations, whereas red on black and black on red are bad combinations. (MacNeil, 1965).

The following rules are listed for making targets more visible against their background. (Meister and Sullivan, 1969; VanCott and Kinkade, 1972).

(1) Choose a color that contrasts with colors in the background.

(2) Choose a brightness that differs as much as possible from the background.

(3) Use as large an area of solid color as possible.

(4) Divide targets that will be seen against different backgrounds into two contrasting colors, so that one of the two colors will contrast with most backgrounds. Good color pairs are white and red, bright yellow and black, bright yellow and blue, and bright green and red.

The research on color coding has primarily been based on results in which relatively small, discrete, geometric forms have been used. Use of color coding for large irregular areas, such as is found with layer tints needs to be empirically investigated (see Lyons, 1914 for a review of some of the many ways in which color coding has been used for layer tints).

Regarding nonredundant use of brightness coding, when viewing conditions are good it is recommended that no more than four brightness steps be used for coding; (Honigfeld, 1964; VanCott and Kinkade, 1972); under other viewing conditions it is suggested that two brightness steps be used. (Honigfeld, 1964; Meister and Sullivan, 1969, VanCott and Kinkade, 1972).

Brightness coding of small discrete symbols scattered over a map may be more difficult to discriminate than would brightness coding of large adjacent areas indicating elevation. One problem with brightness coding is that it is affected by the level of ambient illumination. (Meister and Sullivan, 1969; VanCott and Kinkade, 1972.

Simultaneous contrast may cause the edge of a light area that is adjacent to a darker area to appear lighter than it otherwise would. The effects of simultaneous contrast are largely eliminated if contrasting areas are outlined in black. (Robinson, 1952).

Shape Coding

Shape coding can be subdivided into iconic representation and arbitrary representation. In iconic representation the symbol "looks like" the feature it represents - it may simply be a pictorial representation of the "real thing." (Huggins and Entwisle, 1974). An example of iconic representation is shaded relief which is a two-dimensional pictorial portrayal of three-dimensional terrain. An example of an iconic discrete symbol is use of the black square with a cross on top to represent a church. A good example of arbitrary representation is the alphanumeric symbol.

Many symbols have both arbitrary and iconic characteristics. A circle representing a city may be arbitrary in that the geometric form bears no physical or logical relationship to the outline of the city. However, it is iconic also if the size of the circle is correlated with the physical or population size of the city.

Sinuosities in the line symbol for a road represent curves and bends, but coding for the type of road is arbitrary. The degree of iconicity can be dependent on the particular population that is utilizing the symbol. Inexperienced map users may see contour lines as a jumble of lines, whereas some experienced map readers report that they can see the contours "stand out" from the map to give a three-dimensional portrayal of the landforms that they represent.

Iconicity in visual symbols is not restricted to shape. Color coding is sometimes iconic (i.e., green for vegetation and blue for water). A number of literature reviews suggest that shape coding should be iconic. (Barmack and Sinaiko, 1966, Honigfeld, 1964; Meister and Sullivan, 1969; VanCott and Kinkade, 1972). The underlying rationale is that such shape-object representations can be easily learned, remembered, and used (because the association is already there). Although the underlying rationale seems as though it should be valid (and certainly must be in some cases), the importance of iconic representations for a particular application remains to be empirically determined.

An iconic symbol in a given map display is not necessarily the shape most easily discriminated from the background or the shape most quickly located.

A number of studies have been undertaken to investigate inconicity in map symbols. In a study investigating degree of inconicity of map symbols already in use, each subject was told to draw his own symbol for 30 map features. (Berry, 1961). Less than 50% of the respondents created symbols similar to standard key symbols for 20 of the 30 features. In 11 cases of the 20, the test group drew the topographic features as three-dimensional objects viewed from ground level, which is in contrast to the conventional cartographic representation presenting nearly all features as if viewed from above.

Another study on iconicity was undertaken to investigate size judgments for different types of symbols (William, R. L., Statistical symbols for maps: Their Design and Relative Values. (AD 101698). Map Laboratory, Yale University, New Haven, CO, March 1956), Some of the findings were:

(1) There is no appreciable difference in size judgments between solid and outline symbols.

(2) There is no appreciable difference in size judgments between solid and patterned symbols.

(3) Symbols drawn to appear to have a third dimension were judged the same as if they were plane symbols.

(4) Addition of color affects judgment of visual equivalence between spot symbols only slightly.

(5) The results indicated that the relationship between perceived size and actual size is nonlinear.

In a related study, the authors also found that the relationship between perceived size and actual size is nonlinear for circles and wedges but that bars should be graduated on a linear basis. (Flannery, 1971).

The vertical exaggeration necessary for a three-dimensional representation of a contoured map to look "realistic" for experienced map readers is described by the equation:

Vertical Exaggeration = 6.87-2.82 log contour interval (feet). (Jenks and Caspall, 1967).

Although iconic symbols utilize a preestablished association between the symbol and its referent, judicious use of alphanumeric symbols can sometimes duplicate this advantage.

For example, consider the use of the letter "F" to represent forest and "G" to represent grassland. Alphanumerics have the advantage of being able to communicate precise values and, unlike size coding, which is often iconic, are unaffected by map scale providing that the map scale allows use of a size of alphanumerics that can be read easily.

For some uses, redundant coding of features using color coding plus iconic shape coding might prove very effective.

Iconic shape coding may decrease the time required for an individual to learn the association between the shape and what it represents, whereas redundant use of color may decrease the effect of orientation upon symbol recognizability.

The fact that addition of color coding to shape coding significantly speeds location time also suggests that redundant use of color and iconic shape coding might prove very effective.

Redundant use of color coding should be avoided when small symbol size precludes quick and accurate recognition of the color, when legibility of the symbol is seriously affected, or when typical conditions of illumination are inadequate for color vision.

The most important category of arbitrary shape symbol is the alphanumeric symbol. Permutations and combinations of alphanumeric symbols, including words and names, may be used to code an unlimited number of items.

In choosing between alternative fonts of alphanumeric symbols, the primary consideration is legibility. Legibility tests are made by deteriorating the viewing conditions until errors occur and then noting the number of errors and their distribution among symbols. (Showman, 1966).

Conditions can be deteriorated by reducing brightness of both symbol and background, by blurring the symbols, by reducing exposure time, by reducing size, etc. Fonts which yield high legibility can be specified. (Carel, Hershberger, Herman, and McGrath, 1974a; Honigfeld, 1964; McCormick, 1970; Shurtleff, 1966, VanCott and Kinkade, 1972).

Another type of shape coding that is frequently arbitrary is pattern coding. Compound color and pattern coding has been used effectively (see earlier discussion in section on color coding (Kuehler, 1964)) and allows assignment of several meanings to the same color.

Although not much map-related research was done on pattern coding, one notes that patterns made up of widely spaced discrete symbols, as used for symbolizing deciduous woods on military maps, are not suitable for indicating relatively small stands of trees or precise localization of the boundaries of the forest. If precise localization is desired, discrete symbols must be supplemented with boundary lines, or a more closely spaced, continuous pattern achieved.

Area Size Coding

In making up a size code, the designer should pick the upper and lower limits of the scale and then decide how many steps there are to be. The suggested maximum number of steps for use in size coding is five (Barmack and Sinaiko, 1966); VanCott and Kinkade, 1972); and a safe upper limit on the number of steps for use in size coding is three (Barmack and Sinaiko, 1966; Meister and Sullivan, 1969).

To insure good discriminability, values should be spaced equally on a logarithmic rather than a linear scale because they are less likely to be confused. (Meister and Sullivan, 1969; VanCott and Kinkade, 1972). For information on iconic size coding see the previous discussion on iconic shape coding.

Size coding has disadvantages as compared with other codes in that considerable space is required and location time is longer than for colors and shapes. (Barmack and Sinaiko, 1966). The range of sizes on a given map is related to scale in that a given symbol covers progressively more terrain as map scale decreases.

TECHNIQUES USED IN MAP ASSESSMENT

An important aspect of map design - easily overlooked - as assessment or evaluation of map products. An appreciation of the limitations of the different techniques for assessing map products is necessary for evaluating studies comparing the efficacy of different types of maps.

Assessment is closely related to map design as it forces one to think of the map function or purpose, also a primary consideration in map design. Three basic techniques for evaluation of maps are opinion sampling, theoretical analysis, and empirical testing.

Opinion Sampling

In opinion sampling a map product or series of map products is given to users or "experts", who are asked for opinion on how well the map satisfies, or will satify, extant or future needs.

Typical opinion sampling is generally thought of as limited to the use of questionnaires. However, this technique is far more flexible. For example, in one study pilots rated the usefulness for navigation of terrain features shown both in a film during simulated flight and on aeronautical charts covering the same areas as the simulated flight.

The authors carried out a number of analyses including an analysis of selection rates for inclusion of terrain features in aeronautical charts as contrasted with the rated visual utility of these terrain features.

Even when opinion is sampled with a questionnaire, this type of assessment is not as simple as it might seem and a questionnaire, if used, must be designed carefully to avoid misleading or loaded questions.

The biggest difficulty with opinion sampling as a means of assessing map products is that this technique measures user or expert opinion on how well the map works, which features should be portrayed, how they should be represented, etc., rather than actual performance with map products.

There are a number of reasons why favorable general opinion of a map product is not always positively correlated with favorable numerical measurement of performance. Opinion sampling may be misleading because:

a. Members of a sample may influence one another's opinion (especially true for group leaders).

b. Familiar procedures and familiar equipment are often favored simply because they are familiar.

c. Users may be reluctant to express extreme opinions or may be trying to "please."

d. Users may not be able to assess how well the map product is working or may not have sufficient experience with the map product to give a valid opinion.

Although opinion sampling has serious limitations as a means for assessing the worth of map products, opinion sampling well-conducted is a valuable supplement to other means of assessment because:

a. It may indicate degree of user acceptance of the product.

b. It may reveal deficiencies and the cause of deficiencies in the map product that may not be apparent from other means of assessment.

c. It is relatively inexpensive and may be carried out rather quickly.

When monetary or time factors rule out empirical evaluation, a well-designed survey may be the only practical means for assessment.

Theoretical Analysis

Theoretical assessment of a map product is an attempt to predict how well it will function in a given situation by analysis of how the map would be used, the physical characteristics of the map, previous performance with similar maps, etc.

The major difficulty with this kind of assessment is that in practice it is rarely possible to specify the factors and how they might interact to yield a given level of performance.

Although theoretical analysis alone is probably not sufficient for assessment, it may indicate some deficiencies in a given type of map product, and is a necessary first step for designing an empirical evaluation of map products.

Empirical Analysis

Empirical analysis is testing of the map product based on measures of actual performance with the map product. Where prediction or assessment of performance is critical, there is no substitute for empirical analysis of the map product.

There is a great variety in tasks in which maps are utilized, in the military personnel engaged in such tasks, and in the methods by which the tasks are performed. Ideally, prior to selection of test items, information must be gathered which:

- Identifies personnel using maps.
- Specifies the task being performed.
- Determines how they are performed. (Wheaton, Zavala, & VanCott, 1967).

Given this analysis, two basic approaches can be undertaken to empirical assessment of maps. The first approach is to select a subset of tasks representative of what users do with maps "in the field." Subjects are required to perform the tasks as they are actually performed in an operational setting. Performance is evaluated in terms of degree of successful completion of the operational task. One difficulty with this approach is that for some kinds of maps, measures of performance in the actual situation may be impractical. This is often the case for aeronautical charts. Performance with the map product may have to be measured using a simulation of the typical situation in which the map is employed. There is always the danger that some key element is missing from the simulation and that the results are misleading.

Another drawback of this approach is that many of these tasks are complex and require a number of skills in addition to those involved in interpretation of map products. The performance on a given task may be more influenced by these non-mapreading skills than by difference in ability to utilize different map products and the effects of the map variable may be masked.

The advantage of this approach is that it measures the performance of the man-map system in an approximation to the "real life" situation. If the approximation to the "real life" situation is good then one gets a prediction as to how the man-map system will function in the actual situation in which the map will be employed i.e., predictive validity.

In the second approach, the tasks are devised so as to measure the map reading skills underlying operational use of map products. The tasks employed may not be closely related to what the user does in the field. Performance is measured in terms of how accurately and quickly information is extracted from a given map product. The disadvantage of this approach is that the results may have little predictive validity for how the man-map system will function in the actual situation in which the map is to be used. The advantage of this approach is that it provides the most direct evaluation of map products by obtaining measures of how well alternative map products provide information.

For example, two contour maps of an area can be compared in terms of the speed and accuracy with which people can identify landforms. There may be no other criterion for saying that both maps contain usable portrayals of features for a given user population.

Regardless of the approach taken, when two topographic representations are compared and one is found to be superior using a particular assessment procedure, there are a number of generalization problems. (See Adams, 1966). The results might have been different if:

- Different representative maps had been used.
- Different areas had been portrayed on the map product.
- Different assessment tasks or items had been chosen.
- Different test populations in terms of training and underlying skills had been used.

The fourth variable, training and underlying skills, is easily overlooked when the focus is on the topographic map. The information transmission characteristics for the map product are not fixed characteristics of the particular map product. They are also dependent on subject variables. A highly motivated subject may be able to extract a great deal of information from a given map, whereas a poorly motivated subject may not be willing to expend the necessary effort. A highly trained subject with high ability in pattern analysis might be able to extract a great deal of information concerning relief from the pattern of contour lines portraying terrain features, whereas for a moderately trained subject with low ability in pattern analysis, the contour lines might represent only clutter.

OVERVIEW OF RESEARCH COMPARING DIFFERENT KINDS OF MAPS

Several studies have been carried out to compare photo-based map products with conventional line maps. (Berry, 1960; Hill, 1974; MAPRO, 1973; Wheaton, Zavala and VanCott, 1967). Different tasks were used in these studies including object location, object identification, terrain visualization, height estimation, intervisibility estimation, direction orientation, self-location, field-to-map location, map-to-field object identification, route following, and route planning tasks.

The best photo-based maps produce performance comparable to that with standard-line maps now in use. Whether this is the case because the different types of maps transmit information equally well or because variables not related to maps are the more critical factor is not clear.

Enhancements of roads, railways, and hydrography on orthophoto-maps improves performance on a number of tasks where this information is relevant. (Hill, 1974; Wheaton, et al., 1967).

Photo-based maps have an advantage over line maps in ease of updating and rapidity of production. (Hayes, 1966). Presumably this advantage would be lessened by the time taken for enhancement of map features.

The importance of differences in what orthophoto-maps and line maps portray does not seem to have been investigated. For example, in cultivated areas the photo-based maps routinely show different patterns of fields giving a kind of mosaic, whereas this type of information could only be portrayed on standard-line maps with a great deal of difficulty and effort.

How valuable is this type of information for different map functions? How much seasonal variation does it show, and how is this related to ease of updating and rapidity of production? At what scales do different types of information show up best?

An analysis of what photo-based maps portray as contrasted with standard-line maps does not seem to be in the map literature.

A survey undertaken to specify user requirements pertinent to relief portrayal indicated that 24.7% of Army users reported having difficulty interpreting relief from contours, and 50.2% of map users resorted to hand application of layer tints - 16.7% to alleviate their difficulty in interpreting relief from contours and 30.3% to accentuate the military characteristics of the terrain (Skop, 1958). In a further evaluation, users were provided with prototype maps consisting of contours augmented with shaded relief, contours augmented with layer tints, and contours alone. The prototype maps covered areas familiar to the users. The majority of users, 63.5%, stated that the most effective manner of relief portrayal on large-scale maps was contours augmented with layer tints. A similar preference, 57.7%, was expressed for layer tinting with a 1:250,000 scale map.

The results from a study referred to earlier suggest use of an exaggeration ratio:

Vertical Exaggeration = 6.87-2.28 log contour interval (feet)

for "realistic" three-dimensional representation of large-scale contoured maps (1:24,000 and 1:31,680). The authors recommend that for small scales, the contour interval be divided by the ratio between the 31,680 scale and the smaller scale, but there is no empirical justification for these procedures. (Jenks and Caspall, 1967).

Another study was undertaken to investigate whether the use of the shaded-relief technique for terrain representation results in an increase in the time necessary to extract required elements of nonterrain information from the map. (DeLucia, 1972). When the relief formats of contour line and contour line plus shaded relief were compared, the addition of shaded relief to contour lines was found to increase the time necessary for extracting nonrelief-related information from the map, although the effect was small. Accuracy was unaffected.

One study, using the survey technique compared the Military Topographic Standard Map and the experimental Air Movement Data Map, both at 1:50,000 scale. (Huizar, 1972). The users who evaluated the maps made a number of suggestions for both types of map. Some of their comments that might warrant further consideration are listed below:

(1) 1:50,000 map scale is desired by ground and aviation personnel.

(2) Map format should allow rapid updating.

(3) Presentation of vegetation by percentage of canopy cover is desirable.

(4) Contour lines and some other symbols are difficult to view under artificial red lighting because of the colors used.

(5) Marginal information explaining interpretation of contours, i.e., depression, cuts, and fills, would be helpful.

(6) Highlighting cultural items utilizing pictorial symbols is a desirable innovation.

(7) The presentation of improved and unimproved roads by addition of color to indicate type of surface and width is desirable.

In a study to define the accuracy expected in position location tasks with maps of different scales, subjects were transported in a jeep to various pre-selected positions. Each subject plotted the locations of the terrain positions on the two map scales, 1:25,000 and 1:250,000. Significant differences in error of location were found for the two map scales. Average ground errors obtained with the two map scales, 143 and 1411 m respectively, were almost directly proportional to the ratio between the map scales i.e., a factor of 10. In terms of distance on the map from the indicated terrain position, the mean error for the two maps was approximately .56 cm. (Edmonds and Wright, 1965).

A study was undertaken to compare chip (slide) mode of displaying maps vs. hard copy map displays (map chips are photo transparencies mounted as slides, usually 7 by 10 cm).

In this study, image interpreters had to match imagery to a reference map and locate map coordinates of a point marked on the imagery. Display of the reference map on a screen instead of by hardcopy increased time taken by image interpreters to match imagery to the appropriate area and to determine map coordinates of a point on the imagery.

The longer time required for map chips was attributable to the need to study displays of two chips when the image area lay on the boundary of one or both chips. (Laymon, 1966).

Freedom to orient an image relative to a map display did not affect the time taken to match the imagery to the map or to locate the map coordinates of a point on the imagery.

Another study tested the general principle that cartographic information, having no visual correlate in the real world, would be of no value for pilot orientation. (McGrath, Osterhoff, and Borden, 1964).

Proper names of towns, rivers, and bodies of water have no visual correlate that can be seen from the air and consequently would not be expected to aid geographic orientation.

The authors found no significant difference between orientation performance on simulated flights using a standard Sectional Aeronautical Chart and on simulated flights using a Sectional Aeronautical Chart from which all place names had been removed.

The authors also found that changing scale via photographic enlargements had no effect on geographic orientation, presumably because photographic enlargement did not change information content of the aeronautical chart.

In another study, geographic orientation in aircraft pilots using standard color-coded charts and achromatic versions of these charts was compared. (Osterhoff, Earl, and McGrath, 1966). Geographic orientation performance of four groups of pilots was measured under conditions of simulated flight.

The first group used a full color standard sectional chart; the second group, a graytone version; the third group, a black and white line version; and the fourth group, a blank version. The blank chart was a graytone chart in which the inscribed corridor was completely devoid of topographic information so that navigation could be based only on dead reckoning.

Pilots who used the achromatic graytone and color charts performed significantly poorer than pilots using color charts, but better than pilots using blank charts. Pilot comments upon and ratings of the different charts indicated that the primary reasons for the inferiority of achromatic charts were:

(1) Categories of topographic information were difficult to differentiate.

(2) Reliance on natural landmarks had to be abandoned in favor of reliance on cultural landmarks.

(3) Pilots had to spend too much time studying the charts during flight.

(4) The vertical development of the terrain was poorly portrayed.

The authors concluded that navigation display systems that lack color capability cannot effectively employ existing color-coded aeronautical charts. Specifically designed achromatic graphics will be required for such systems.

The next study was designed to analyze information requirements of pilots and information content of aeronautical charts. (McGrath and Borden, 1969). Since the authors make a number of suggestions for design of aeronautical charts, the study is summarized in detail.

In this study, pilots were required to rate the usefulness of the terrain features shown in the film during simulated low altitude flight. The film showed a continuous scene of the forward visual field as seen from the cockpit of an aircraft flying with an average ground speed of 556 kn/h and an average terrain clearance altitude of 61 m.

Each pilot made judgments of the utility of the feature as a visual cue for orientation and navigation. The visual utility of a feature was measured by the percentage of pilots who indicated it would be generally useful or very useful.

A quantitative index of the rated usefulness of each feature portrayed on the Sectional Aeronautical Chart, the USAF Pilotage Chart, and the USAF Operational Navigation Chart was also obtained. These are small scale charts (1:500,000-1:1,000,000) in which the third dimension is portrayed using contour lines, spot elevations, gradient tints, and for two of the maps, shaded relief.

The cartographic utility of a feature was measured by the percentage of pilots who indicated it would be useful after viewing it on a map. The authors also measured the selection rate, i.e., the percentage of the available features in a given category that were portrayed on the charts.

Some significant results of the study were as follows:

(1) The pilots rated waterbodies, watercourses, and paved roads as useful features for orientation.

(2) Linear size of the feature had a strong effect on visual utility, cartographic utility, and selection rate. These measures all increased as linear size increased. Area size had a strong effect on the visual utility and selection rate for bodies of water.

(3) The greater the number of buildings in a community, the greater the visual utility and the higher the selection rate.

(4) Irregularly shaped features generally had higher selection rates and higher visual utility than features with geometric shapes, but this difference was partly attributable to differences in area size. Visual utility of railroads and watercourses increased as sinuosity of the features increased.

(5) Contrast had a strong effect on the visual utility of features, and the effect was consistent across all categories. The higher the contrast between the feature and its background, the more useful it was judged as a visual cue to orientation. Contrast had no systematic effect on cartographic utility or selection rate.

Another experiment was undertaken to investigate the effects of resolution, display luminance, ambient illumination, vibration, and cartographic characteristics such as clutter and size displayed symbols upon symbol legibility for airborne map displays. (Carel, Hershberger, Herman, and McGrath, 1974a).

The tasks used in the experiment were simple recognition tasks consisting of identification of symbols including alphanumeric symbols, counting tasks, etc. Threshold legibility for alphanumeric symbols refers to the visual angle subtended by the symbol when it was read or spelled with no subsequent error.

In this study, visual angle requirements for threshold legibility increased by about 100% with the more extreme conditions of resolution and total display luminance. Within the ranges used in this experiment, luminance had a larger effect on legibility than did contrast.

Visual angle requirements for threshold legibility size increased from 9.73 to 12.33 arc minutes as clutter changed from low to high. Visual angle requirements were lowest for lowercase words, highest for numerals, with uppercase words being intermediate. Vibration increased the visual angle required for threshold legibility.

Those contrast luminance conditions which provided the poorest static legibility were most affected by vibration. These results are used to give detailed quantitative descriptions of design criteria for airborne map displays. (Carel, Hershberger, Herman, and McGrath, 1974b).

SUMMARY

Three important determinants of the design of topographic maps are scale, interrelatedness of symbols, and a body of standardized symbols and modes of coding. Map scale is an important determinant of fidelity.

If the same rules are used to represent features on maps of different scale, then the larger scale map will have greater fidelity because small scale necessitates selection, simplification, and magnification of features. Enlarging or reducing a map photographically will not alter the fidelity of a map.

The problems of clutter and overlapping symbols occur when too much information is crowded onto a map. Clutter can be reduced by presenting information on separate, subsidiary maps, or by the use of coding to differentiate information.

Visual coding techniques applicable to maps are color coding, shape coding, and area-size coding. Coding categories may also be based on the number of visual codes used and the way in which they are combined.

Color coding aids in identification and search, and decreases location time. Redundant coding using both shape and color decreases location time over use of shape coding alone. Some authorities suggest that shape coding should be iconic since iconic shapes can be easily learned, remembered, and used. However, alphanumeric symbols also can be designed for easy learning and have the advantage of great flexibility. Area-size coding requires considerable space, and location time is larger than with shape or color coding.

Three assessment techniques can be used to evaluate maps: opinion sampling, theoretical analysis, and empirical analysis. Opinion sampling is relatively inexpensive and easily carried out, but does not measure actual performance. Theoretical analysis provides a necessary first step but is limited in that it is rarely possible to specify all factors that might influence performance. Empirical analysis measures actual performance with the map product, either in assessing direct or simulated performance with the maps, or by measuring the map-reading skills which underlie actual performance.

The best photo-based maps produce performance comparable to that with conventional line maps now in use. However, the importance of differences in what orthophoto maps and line maps portray does not seem to have been assessed.

Some Army users have reported difficulty interpreting topographic relief from contour lines. In one survey, a majority of Army users stated that the most effective manner of relief portrayal augmented contour lines with layer tinting.

Studies on airborne map displays produced a body of suggestions for design of future airborne maps on information requirements of pilots, effects of movement, and map legibility.

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1 USA Armor Sch, Ft Knox, ATTN: ATSB-DI-E
1 USA Armor Sch, Ft Knox, ATTN: ATSB-DT-TP
1 USA Armor Sch, Ft Knox, ATTN: ATSB-CD-AD
2 HQUSACDEC, Ft Ord, ATTN: Library
1 HQUSACDEC, Ft Ord, ATTN: ATEC-EX-E-Hum Factors
2 USAEEC, Ft Benjamin Harrison, ATTN: Library
1 USAPACDC, Ft Benjamin Harrison, ATTN: ATCP-HR
1 USA Comm-Elect Sch, Ft Monmouth, ATTN: ATSN-EA
1 USAEC, Ft Monmouth, ATTN: AMSEL-CT-HDP
1 USAEC, Ft Monmouth, ATTN: AMSEL-PA-P
1 USAEC, Ft Monmouth, ATTN: AMSEL-SI-CB
1 USAEC, Ft Monmouth, ATTN: C, Facl Dev Br
1 USA Materials Sys Anal Agcy, Aberdeen, ATTN: AMXSY-P
1 Edgewood Arsenal, Aberdeen, ATTN: SAREA-BL-H
1 USA Ord Ctr & Sch, Aberdeen, ATTN: ATSL-TEM-C
2 USA Hum Engr Lab, Aberdeen, ATTN: Library/Dir
1 USA Combat Arms Tng Bd, Ft Benning, ATTN: Ad Supervisor
1 USA Infantry Hum Rsch Unit, Ft Benning, ATTN: Chief
1 USA Infantry Bd, Ft Benning, ATTN: STEBC-TE-T
1 USASMA, Ft Bliss, ATTN: ATSS-LRC
1 USA Air Def Sch, Ft Bliss, ATTN: ATSA-CTD-ME
1 USA Air Def Sch, Ft Bliss, ATTN: Tech Lib
1 USA Air Def Bd, Ft Bliss, ATTN: FILES
1 USA Air Def Bd, Ft Bliss, ATTN: STEBD-PO
1 USA Cmd & General Stf College, Ft Leavenworth, ATTN: Lib
1 USA Cmd & General Stf College, Ft Leavenworth, ATTN: ATSW-SE-L
1 USA Cmd & General Stf College, Ft Leavenworth, ATTN: Ed Advisor
1 USA Combined Arms Cmbt Dev Act, Ft Leavenworth, ATTN: DepCdr
1 USA Combined Arms Cmbt Dev Act, Ft Leavenworth, ATTN: CCS
1 USA Combined Arms Cmbt Dev Act, Ft Leavenworth, ATTN: ATCASA
1 USA Combined Arms Cmbt Dev Act, Ft Leavenworth, ATTN: ATCACO-E
1 USA Combined Arms Cmbt Dev Act, Ft Leavenworth, ATTN: ATCACC-CI
1 USAECOM, Night Vision Lab, Ft Belvoir, ATTN: AMSEL-NV-SD
3 USA Computer Sys Cmd, Ft Belvoir, ATTN: Tech Library
1 USAMERDC, Ft Belvoir, ATTN: STSFB-DQ
1 USA Eng Sch, Ft Belvoir, ATTN: Library
1 USA Topographic Lab, Ft Belvoir, ATTN: ETL-TD-S
1 USA Topographic Lab, Ft Belvoir, ATTN: STINFO Center
1 USA Topographic Lab, Ft Belvoir, ATTN: ETL-GSL
1 USA Intelligence Ctr & Sch, Ft Huachuca, ATTN: CTD-MS
1 USA Intelligence Ctr & Sch, Ft Huachuca, ATTN: ATS-CTD-MS
1 USA Intelligence Ctr & Sch, Ft Huachuca, ATTN: ATSI-TE
1 USA Intelligence Ctr & Sch, Ft Huachuca, ATTN: ATSI-TEX-GS
1 USA Intelligence Ctr & Sch, Ft Huachuca, ATTN: ATSI-CTS-OR
1 USA Intelligence Ctr & Sch, Ft Huachuca, ATTN: ATSI-CTD-DT
1 USA Intelligence Ctr & Sch, Ft Huachuca, ATTN: ATSI-CTD-CS
1 USA Intelligence Ctr & Sch, Ft Huachuca, ATTN: DAS/SRD
1 USA Intelligence Ctr & Sch, Ft Huachuca, ATTN: ATSI-TEM
1 USA Intelligence Ctr & Sch, Ft Huachuca, ATTN: Library
1 CDR, HQ Ft Huachuca, ATTN: Tech Ref Div
2 CDR, USA Electronic Prvg Grd, ATTN: STEEP-MT-S
1 CDR, Project MASSTER, ATTN: Tech Info Center
1 Hq MASSTER, USATRADOC, LNO
1 Research Institute, HQ MASSTER, Ft Hood
1 USA Recruiting Cmd, Ft Sherdian, ATTN: USARCPM-P
1 Senior Army Adv., USAFAGOD/TAC, Elgin AF Aux Fld No. 9
1 HQ USARPAC, DCSPER, APO SF 96558, ATTN: GPPE-SE
1 Stimson Lib, Academy of Health Sciences, Ft Sam Houston
1 Marine Corps Inst., ATTN: Dean-MCI
1 HQUSMC, Commandant, ATTN: Code MTMT 51
1 HQUSMC, Commandant, ATTN: Code MPI-20
2 USCG Academy, New London, ATTN: Admission
2 USCG Academy, New London, ATTN: Library
1 USCG Training Ctr, NY, ATTN: CO
1 USCG Training Ctr, NY, ATTN: Educ Svc Ofc
1 USCG, Psychol Res Br, DC, ATTN: GP 1/62
1 HQ Mid-Range Br, MC Det, Quantico, ATTN: P&S Div

1 US Marine Corps Liaision Ofc, AMC, Alexandria, ATTN: AMCGS–F
1 USATRADOC, Ft Monroe, ATTN: ATRO–ED
6 USATRADOC, Ft Monroe, ATTN: ATPR–AD
1 USATRADOC, Ft Monroe, ATTN: ATTS–EA
1 USA Forces Cmd, Ft McPherson, ATTN: Library
2 USA Aviation Test Bd, Ft Rucker, ATTN: STEBG–PO
1 USA Agcy for Aviation Safety, Ft Rucker, ATTN: Library
1 USA Agcy for Aviation Safety, Ft Rucker, ATTN: Educ Advisor
1 USA Aviation Sch, Ft Rucker, ATTN: PO Drawer O
1 HQUSA Aviation Sys Cmd, St Louis, ATTN: AMSAV–ZDR
2 USA Aviation Sys Test Act., Edwards AFB, ATTN: SAVTE–T
1 USA Air Def Sch, Ft Bliss, ATTN: ATSA TEM
1 USA Air Mobility Rsch & Dev Lab, Moffett Fld, ATTN: SAVDL–AS
1 USA Aviation Sch, Res Tng Mgt, Ft Rucker, ATTN: ATST–T–RTM
1 USA Aviation Sch, CO, Ft Rucker, ATTN: ATST–D–A
1 HQ, USAMC, Alexandria, ATTN: AMXCD–TL
1 HQ, USAMC, Alexandria, ATTN: CDR
1 US Military Academy, West Point, ATTN: Serials Unit
1 US Military Academy, West Point, ATTN: Ofc of Milt Ldrshp
1 US Military Academy, West Point, ATTN: MAOR
1 USA Standardization Gp, UK, FPO NY, ATTN: MASE–GC
1 Ofc of Naval Rsch, Arlington, ATTN: Code 452
3 Ofc of Naval Rsch, Arlington, ATTN: Code 458
1 Ofc of Naval Rsch, Arlington, ATTN: Code 450
1 Ofc of Naval Rsch, Arlington, ATTN: Code 441
1 Naval Aerospc Med Res Lab, Pensacola, ATTN: Acous Sch Div
1 Naval Aerospc Med Res Lab, Pensacola, ATTN: Code L51
1 Naval Aerospc Med Res Lab, Pensacola, ATTN: Code L5
1 Chief of NavPers, ATTN: Pers-OR
1 NAVAIRSTA, Norfolk, ATTN: Safety Ctr
1 Nav Oceanographic, DC, ATTN: Code 6251, Charts & Tech
1 Center of Naval Anal, ATTN: Doc Ctr
1 NavAirSysCom, ATTN: AIR–5313C
1 Nav BuMed, ATTN: 713
1 NavHelicopterSubSqua 2, FPO SF 96601
1 AFHRL (FT) William AFB
1 AFHRL (TT) Lowry AFB
1 AFHRL (AS) WPAFB, OH
2 AFHRL (DOJZ) Brooks AFB
1 AFHRL (DOJN) Lackland AFB
1 HQUSAF (INYSD)
1 HQUSAF (DPXXA)
1 AFVTG (RD) Randolph AFB
3 AMRL (HE) WPAFB, OH
2 AF Inst of Tech, WPAFB, OH, ATTN: ENE/SL
1 ATC (XPTD) Randolph AFB
1 USAF AeroMed Lib, Brooks AFB (SUL–4), ATTN: DOC SEC
1 AFOSR (NL), Arlington
1 AF Log Cmd, McClellan AFB, ATTN: ALC/DPCRB
1 Air Force Academy, CO, ATTN: Dept of Bel Scn
5 NavPers & Dev Ctr, San Diego
2 Navy Med Neuropsychiatric Rsch Unit, San Diego
1 Nav Electronic Lab, San Diego, ATTN: Res Lab
1 Nav TrngCen, San Diego, ATTN: Code 9000–Lib
1 NavPostGraSch, Monterey, ATTN: Code 55Aa
1 NavPostGraSch, Monterey, ATTN: Code 2124
1 NavTrngEquipCtr, Orlando, ATTN: Tech Lib
1 US Dept of Labor, DC, ATTN: Manpower Admin
1 US Dept of Justice, DC, ATTN: Drug Enforce Admin
1 Nat Bur of Standards, DC, ATTN: Computer Info Section
1 Nat Clearing House for MH–Info, Rockville
1 Denver Federal Ctr, Lakewood, ATTN: BLM
12 Defense Documentation Center
4 Dir Psych, Army Hq, Russell Ofcs, Canberra
1 Scientific Advsr, Mil Bd, Army Hq, Russell Ofcs, Canberra
1 Mil and Air Attache, Austrian Embassy
1 Centre de Recherche Des Facteurs, Humaine de la Defense Nationale, Brussels
2 Canadian Joint Staff Washington
1 C/Air Staff, Royal Canadian AF, ATTN: Pers Std Anal Br
3 Chief, Canadian Def Rsch Staff, ATTN: C/CRDS(W)
4 British Def Staff, British Embassy, Washington
1 Def & Civil Inst of Enviro Medicine, Canada
1 AIR CRESS, Kensington, ATTN: Info Sys Br
1 Militaerpsykologisk Tjeneste, Copehagen
1 Military Attache, French Embassy, ATTN: Doc Sec
1 Medecin Chef, C.E.R.P.A.–Arsenal, Toulon/Naval France
1 Prin Scientific Off, Appl Hum Engr Rsch Div, Ministry of Defense, New Delhi
1 Pers Rsch Ofc Library, AKA, Israel Defense Forces
1 Ministeris van Defensie, DOOP/KL Afd Sociaal Psychologische Zaken, The Hague, Netherlands